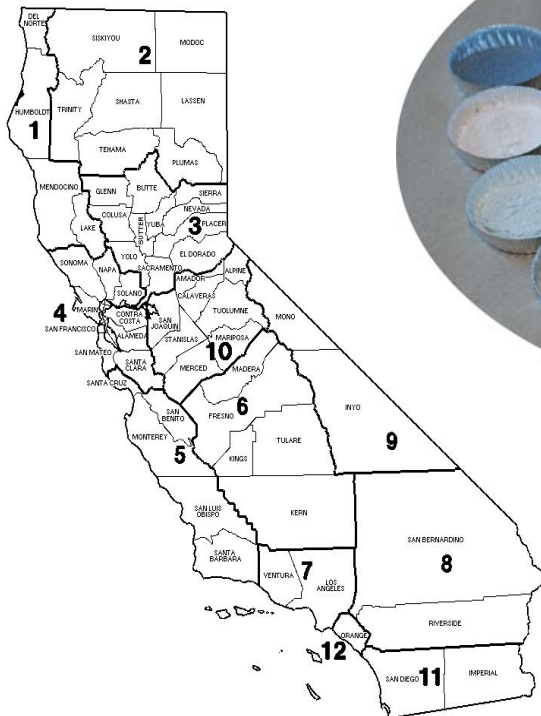




STATE OF CALIFORNIA  
DEPARTMENT of TRANSPORTATION  
DIVISION OF ENGINEERING SERVICES  
MATERIALS AND ENGINEERING SERVICES

# 21<sup>st</sup> CENTURY CONCRETE GUIDELINES

## Guidelines for the Design & Inspection of Concrete



Use these Guidelines with the current Section 90 “Portland Cement Concrete” of the Caltrans Standard Specifications.

April 2010



## DISCLAIMER

These 21<sup>ST</sup> Century Concrete Guidelines are published by Caltrans and are intended for use by Caltrans personnel. Engineers and agencies outside of Caltrans may use these guidelines at their own discretion. Caltrans is not responsible for any work performed by non-Caltrans personnel using this guide.

Caltrans intends these guidelines as a resource for all personnel engaged in rigid pavement and/or structural concrete design and construction. These guidelines contain information intended to help design and construction personnel achieve the proper mix for a specific need. However, these guidelines are not contract documents. They impose no obligations or requirements on contractors. Resident Engineers and other Caltrans personnel who administer Caltrans contracts must never attempt to use these guidelines as a substitute or supplement to the standard specifications and other contract requirements and provisions. The link to the latest version of the guidelines can be found at:

[http://onramp.dot.ca.gov/hq/esc/mets/structure\\_materials/documents/guidelines.pdf](http://onramp.dot.ca.gov/hq/esc/mets/structure_materials/documents/guidelines.pdf)

Questions on these guidelines can be directed to the Structural Materials Representative for your District. The link for the contact information is:

<http://www.dot.ca.gov/hq/esc/translab/osm/smdocuments/structuralmaterialsrepresentatives.pdf>

Questions specific to pavement concrete issues addressed outside of Section 90 specifications can be directed to the Division of Pavement Management.



## ABSTRACT

These *21<sup>st</sup> Century Concrete Guidelines* were developed by the California Department of Transportation (Caltrans). They include several components related to Section 90, “Portland Cement Concrete”. These guidelines assist in concrete design and placement, the nuances relating to the current specification changes, and the different types of supplementary cementitious materials and admixtures allowed. The Guidelines are presented in four sections. Section 1 introduces the reader to Caltrans concrete, provides insight to Caltrans concrete philosophy and includes a list of terms and definitions of importance to the guidelines. Section 2 provides noteworthy specification interpretations and information. Section 3 describes the supplementary cementitious materials and their properties. Section 4 explains the use and properties of chemical admixtures. Sections 2, 3, and 4 are all in a Q & A format. The Appendix includes quick reference sheets for some of the SCM’s allowed in Caltrans concrete and sample calculations for the included specification equations.



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## **SECTION 1. INTRODUCTION**

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### **CALTRANS CONCRETE PHILOSOPHY**

The Caltrans concrete specification philosophy is best described as partially prescriptive and partially performance. Partially prescriptive in that certain minimums and/or maximums set out in the specifications are required to attain desirable characteristics set by Caltrans that are difficult to measure or test in a timely fashion. Partially performance in that after the prescriptive portion has been met, the remaining is based on performance criteria (i.e., compressive strength, flexural strength, and soundness).

The prescriptive portion provides the supplier and or contractor with the flexibility to utilize innovative concrete mixtures to meet the high quality concrete that Caltrans demands. The caveat is that this flexibility necessitates improved quality control. This guideline has been created to assist Caltrans personnel to ensure quality control of concrete mix design based on the Section 90, "Portland Cement Concrete" specifications.

### **SECTION 90 TERMS**

#### **Accelerating Admixture**

A chemical admixture that shortens the amount of time necessary for setting and strength development of concrete.

#### **Admixture Materials**

Materials incorporated in a concrete mix design in addition to cement, supplementary cementitious material (SCM), coarse aggregate, fine aggregate and water that are used to enhance specific properties of the mix. Admixture materials for Caltrans purposes include chemical admixtures such as lithium nitrate, and air-entraining admixtures.

#### **Air Entraining Admixtures**

An admixture material that causes minute air bubbles to be encapsulated in the concrete in order to produce a more workable, frost resistant concrete.

#### **Alkali Silica Reactivity (ASR)**

Reaction between reactive components of aggregate and alkalis in the pore solution of concrete, that could cause expansion and deterioration of concrete.

#### **ASR Inhibiting Admixtures**

A chemical admixture that is typically lithium based and used to control the reactivity of aggregates that cause alkali silica reactivity (ASR).

### **Binary Mix**

A mixture of two cementitious materials, typically portland cement and one SCM. For more information see Section 3 of this document.

### **Blended Cement**

A combination of portland cement and one or more SCM, the combining being done prior to delivery to a concrete batch plant. For Caltrans this is a combination of Type II or Type V cement and SCM produced either by intergrinding portland cement clinker and SCM, by blending portland cement and either finely ground granulated blast furnace slag or finely divided pozzolan, or a combination of intergrinding and blending. These blended cements are classified as Type IS (MS), portland blast-furnace slag cement, or Type IP (MS), portland-pozzolan cement, with (MS) representing moderate sulfate resistance.

### **Cementitious Materials**

For these guidelines this includes portland cement, ground granulated blast furnace slag, fly ash, and ultra fine fly ash, raw or calcined natural pozzolans, metakaolin, silica fume, and rice hull ash, or a combination of any of these materials. All are materials that exhibit binding properties and characteristics similar to portland cement.

### **Chemical Admixtures**

Admixtures that fall under the category of ASTM Designation: C 494 are considered chemical admixtures. This includes water reducing, retarding, water reducing and retarding, shrinkage reducing and accelerating, viscosity modification, and ASR mitigation admixtures. For more information see Section 4 of this document.

### **Class F Fly Ash**

A pozzolan, used as an SCM, that is created as a byproduct of coal burning in power plants. For more information see Section 3 of this document and Appendix A.

### **Coarse Aggregate**

The larger rock in concrete that typically consists of gravel, crushed gravel, crushed rock, reclaimed aggregate, crushed air-cooled iron blast furnace slag, or a combination thereof and ranges in size from aggregate retained on the No. 10 sieve up to 2”.

### **Concrete**

A mixture of cementitious material, water, fine and coarse aggregate combined to form a rock-like mass. Chemical admixtures may also be added.

### **Curing**

Maintaining freshly placed concrete under moisture and temperature conditions for a period of time after placement so the concrete can sufficiently gain its desired properties. Curing assures satisfactory hydration of the cement and hardening of the mix.

### **Fine Aggregate**

The finer rock in concrete that typically consists of natural sand, manufactured sand from larger aggregate, or a combination thereof and ranges in size up to 1/4".

### **Ground Granulated Blast Furnace Slag (GGBFS)**

A glassy, granular material used as an SCM that is created as a byproduct of iron smelting that has been ground into a powder. For more information see Section 3 of this document and Appendix A.

### **Innocuous Aggregate**

An aggregate is considered innocuous for ASR when it is found on the Pre-Qualified Products List. The current Pre-Qualified Products List can be found on the Office of Materials Engineering and Testing Services (METS) website at the following link:

[http://www.dot.ca.gov/hq/esc/approved\\_products\\_list/](http://www.dot.ca.gov/hq/esc/approved_products_list/)

Prior to placement on the above mentioned list, the aggregate must be tested by one the two following test methods:

1. The aggregate is tested in conformance with the requirements in California Test 554 and ASTM Designation: C 1293, the expansion at 1 year is less than or equal to 0.040 percent.
2. The aggregate is tested in conformance with the requirements in California Test 554 and ASTM Designation: C 1260, the average of the expansion at 16 days is less than or equal to 0.15 percent.

### **Lithium Nitrate**

Lithium Nitrate ( $\text{LiNO}_3$ ) is a chemical that can arrest active ASR after placement of concrete or prevent ASR from occurring when added as an admixture to fresh concrete.

### **Metakaolin**

A very finely ground natural pozzolan that is used as an SCM and is derived from the calcination of a high-purity kaolin clay. For more information see Section 3 of this document and Appendix A.

### **Natural Pozzolans**

A naturally occurring material that is typically processed by heat treatment and/or grinding diatomaceous earth (also includes opaline cherts, shales, tuffs, volcanic ashes or pumicites and calcined clays. Natural pozzolans include metakaolin,

calcined clay, and calcined shale. For more information see Section 3 of this document.

### **Portland Cement**

A hydraulic calcium silicate with one or more forms of calcium sulfate in a powder form, that reacts chemically with water to bind materials, such as aggregate, together to form concrete. There are five basic types of portland cement:

- Type I General purpose cement (not specified in Section 90)
- Type II Provides moderate sulfate resistance
- Type III Used when high early strength is required
- Type IV Used when low heat of hydration is required (not specified in Section 90 and not generally available in California)
- Type V Used when high sulfate resistance is required

\*For the purposes of these guidelines all references to cement are short for portland cement unless noted otherwise.

### **Pozzolan**

A finely divided material that reacts with calcium hydroxide to produce materials exhibiting cementitious properties.

### **Reclaimed Aggregate**

Aggregate that has been recovered from plastic concrete by washing away the cementitious material.

### **Recycled Aggregate**

Aggregate that is formed by crushing, sizing, and screening an existing, hardened concrete surface or structure. Note this type of aggregate is only allowed in Caltrans projects as certain backfill materials and aggregate for lean concrete base, and minor concrete.

### **Retarding Admixtures**

A chemical admixture that delays the setting and hardening of concrete.

### **Rice Hull Ash**

A pozzolanic material, that is formed as a by-product of the rice milling process. For more information see Section 2 (90-10), Section 3 and Appendix A of this document.

### **Shrinkage Reducing Admixture**

A chemical admixture that reduces the amount of drying shrinkage in concrete and is typically used in areas where cracks must be minimized for durability reasons.

### **Silica Fume**

A very fine pozzolan, used as an SCM, that is created as a byproduct in the arc furnaces in silicon and ferrosilicon industries. For more information see Section 3 of this document and Appendix A.

### **Structural Materials Representative (SMR)**

The SMR is the single point of contact between the Office of Structural Materials and Construction. The SMR serves as the METS point of contact for issues or questions that Construction may have regarding other offices within METS. It is the SMR's responsibility to provide clear, effective and timely structural materials recommendations to Construction. District boundaries are generally used to define the geographic areas of responsibility for the SMR's. The link to the list of SMR's is:

<http://www.dot.ca.gov/hq/esc/translab/osm/smdocuments/structuralmaterialsrepresentatives.pdf>

### **Supplementary Cementitious Materials (SCM's)**

Materials that on their own or when combined with portland or blended cements exhibit cementitious properties. These materials are naturally occurring, manufactured, or by-products of industrial processes. Typical SCM's are ground granulated blast furnace slag, fly ash, silica fume, rice hull ash, and natural pozzolans such as calcined shale, calcined clay, and metakaolin.

### **Ternary Mix**

A concrete mixture containing three cementitious materials, typically portland cement and two SCM's. For more information see Section 3 of this document.

### **Water Reducing Admixtures**

A chemical admixture that allows for a reduction in the amount of water required to produce concrete with a certain slump. Less water in the mix reduces the water-cement ratio for higher strength, and may reduce the cement content for lower cost, or increases slump or penetration in a concrete mix to improve workability.

## **SECTION 2. Q&A SECTION 90**

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### **90-1 GENERAL**

#### **90-1.01 Description**

**1. Why is the minimum compressive strength set at 2500 psi?**

Since higher volumes of SCM's are allowed in mixes, a lower volume of portland cement is permitted. Because of this lower volume of portland cement, a minimum compressive strength is required for mixes that are not designated by compressive strength.

**2. How many days are allowed for concrete to gain the specified strength?**

Concrete that has a required compressive strength greater than 3600 psi is considered concrete designated by compressive strength. 42 days is allowed for concrete that has a specified compressive strength greater than 3600 psi. 56 days is allowed for concrete that has higher volumes of SCM as defined in SSP S8-C02. This increase in time is allowed as some mixes having higher volumes of SCM's require more time to gain initial strength than mixes without. If the concrete is specified less than 3600 psi, the Engineer has the option of testing concrete at 28 days and is able to accept the concrete if it attains 85% of the minimum required strength.

**3. What is the purpose of the shrinkage test?**

Excessive drying shrinkage can lead to cracking of concrete elements. Caltrans used to indirectly control the shrinkage, in part, by having a drying shrinkage limit on the cement. Beginning in 2008 there is a shrinkage limit on concrete in the most susceptible elements rather than all of the elements.

**4. How is a mix design verified for compliance?**

Appendix B has provided a mix design checklist and examples of checking mix design compliance. This includes the use of all applicable equations.

### **90-2 MATERIALS**

#### **90-2.01 Cementitious Materials**

**5. Why do cementitious materials have to be on the departments Pre-Qualified Products List prior to use, and where is this list located?**

With the specification's further allowance to blend cement and the seemingly endless number of cementitious material sources, a program had to be developed for a higher level of quality assurance. Cementitious materials suppliers submit to Caltrans their quality control plans and monthly tests for specification

compliance. The current Pre-Qualified Products List can be found on the Office of Materials Engineering and Testing Services (METS) website at the following link:

[http://www.dot.ca.gov/hq/esc/approved\\_products\\_list/](http://www.dot.ca.gov/hq/esc/approved_products_list/)

Once at the above web address, use the “Cementitious Materials for use in Concrete” link.

### **90-2.01A Cement**

#### **6. What types of cement are allowed for use according to the specifications?**

Caltrans accepts Type II and V portland cement and Type IS (MS) and IP (MS) blended cements. Type III cements, when specified, are used for high early strength which is typical in the manufacture of precast units for early form release, and rapid strength concrete pavements.

### **90-2.01C Required Use of Supplementary Cementitious Materials**

#### **7. What quantities of SCM’s are required to be used?**

Any combination of SCM’s satisfying Equation’s 1 or 3, as applicable, of Section 90-2.01C, meets the minimum requirements for the amount of SCM to be used.

#### **8. What is the purpose of Equations 1 and 2 in the Section 90 Standard Specifications?**

Equation 1 makes it possible to have ternary mixes and beyond (more than 3 cementitious materials) and also eliminates the cap previously placed on SCM’s. This allows for an infinite number of different mix designs while establishing the minimum SCM requirements based on the minimum amount of cementitious material.

Equation 2 limits cement to a percentage of the minimum specified amount of cementitious material. Essentially if the total amount of cementitious material in a mix is increased, it has to be done with SCM’s rather than cement.

#### **9. What effects do the SCM’s have on the concrete that is being produced?**

See Section 3 of this document for further discussion into this question and others involving SCM properties.

#### **10. If the cementitious material content specified is reduced per Section 90-4.05 “Optional Use of Chemical Admixtures” how does this affect the variable MC of equation 1?**

If the cementitious material content is reduced per the above standard, the variable MC should also be reduced to reflect the revised amount of cementitious material. Since TC is the summation of the cementitious materials actually used, there is no impact on equation 3.

**11. What mix design options are available to the contractor?**

The contractor per Section 90-2.01C of the specifications, has the option to use any combination of supplementary cementitious material and portland cement if the expansion of cementitious material and aggregate does not exceed 0.10 percent when tested in conformance with the requirements in ASTM C 1567. This option provides the contractor with mix design flexibility and Caltrans with the ASR protection needed for long term concrete durability and performance.

**12. What are the differences between Equations 1 and 3 of the specifications?**

Equation 1 is for cast in place concrete while Equation 3 is for precast concrete. For general concrete the equation is solved using the specified minimum cementitious material (MC). For precast concrete the equation is solved using the total amount of cementitious material (TC) in the mixture. Using TC allows for the use of more cement giving the precast manufacturer the ability to get transfer strength in hours instead of days. This is necessary to move the precast element safely while also freeing up the mold. Another difference is the value of “X” used for innocuous aggregate.

**13. Are SCM’s required for precast girders?**

The specification requires precast girders and all other precast products and elements to include the use of SCM’s. The exception to this rule is when precast elements use innocuous aggregate per Section 90-2.02. For additional information on innocuous aggregate, see the following section regarding aggregate of these guidelines.

**14. Are there any exceptions to these equations?**

Yes. There are two main exceptions to these equations. First, when the concrete is in a corrosive environment as defined by SSP S8-C04 “Corrosion Control for Portland Cement Concrete.” This SSP makes the mix more prescriptive to ensure durable concrete. The other exception is concrete in a freeze / thaw environment as defined in SSP S8-C05 “Freezing Condition Requirements.” This SSP puts upper limits on the amounts of SCM’s allowed. These SSP’s will appear in Section 8-2 of the project specifications.

**90-2.02 Aggregates**

**15. What is innocuous aggregate and how do I find a source that is innocuous?**

Innocuous aggregate is an aggregate which has been tested per CTM 554 and ASTM Designation: C 1293 or C 1260 and has proven to be non-expansive. For aggregate to be considered innocuous, both fine and coarse aggregates must be on the Pre-Qualified Products List. The current Pre-Qualified Products List can be



found on the Office of Materials Engineering and Testing Services (METS) website at the following link:

[http://www.dot.ca.gov/hq/esc/approved\\_products\\_list/](http://www.dot.ca.gov/hq/esc/approved_products_list/)

Once at the above web address, use the “Aggregates for Concrete” link.

**16. What does innocuous aggregate do to Equations 1 and 3 of Section 90-2.01C?**

For cast in place concrete, having innocuous aggregate reduces the amount of SCM's required to satisfy Equation 1. For precast concrete (Equation 3), innocuous aggregate eliminates the need for SCM's.

**17. Is reclaimed aggregate allowed in Caltrans concrete?**

Yes. Reclaimed aggregate is allowed for coarse aggregate in all Caltrans concrete (90-2.02A) and for coarse and fine aggregate in minor concrete (90-10.02B).

**18. Is recycled aggregate allowed in Caltrans concrete?**

Yes. Recycled aggregate (crushed concrete) is allowed up to 100% in minor concrete only (90-10.02B) as long as it satisfies all aggregate requirements.

**19. What is the difference between “Operating Range” and “Contract Compliance” when applied to cleanness value, sand equivalent, and gradation testing?**

The operating range is the minimum level at which the aggregate being tested is expected to comply. Should the aggregate not meet the operating range requirements but still fall within contract compliance, the current concrete pour shall be accepted. However no further placement will be allowed until the aggregate is back in the operating range. Should the testing fall outside of contract compliance, the concrete placed with that material shall be removed unless deductions are allowed per Section 90-2.02.

## **90-4 ADMIXTURES**

### **90-4.01 General**

**20. What effects do admixtures have on the concrete being produced?**

See Section 4 of this document for further discussion into this question and others involving admixture properties.

### **90-4.03 Admixture Approval**

**21. Where is the Department’s current Pre-Qualified Products List for chemical admixtures located and what is included on this list?**

The current Pre-Qualified Products List can be found on the Office of Materials Engineering and Testing Services (METS) website at the following link:

[http://www.dot.ca.gov/hq/esc/approved\\_products\\_list/](http://www.dot.ca.gov/hq/esc/approved_products_list/)

Once at the above web address, use the “[Chemical Admixtures for Use in Concrete](#)” link. This list includes all approved chemical admixtures, air-entraining admixtures, and lithium nitrate.

**22. I can’t find lithium nitrate on the Departments Pre-Qualified Products List, where are these located?**

Though lithium nitrate is listed separately in the standards, it is considered a Type S chemical admixture under ASTM Designation: C 494. Type S chemical admixtures can be found in the same document mentioned in the previous question.

**90-4.05 Optional Use of Chemical Admixtures**

**23. How are equations 1 and 3 affected if the cementitious material content specified is reduced when using a water-reducing or water-reducing and retarding admixture?**

See question #11 of these guidelines.

**24. What kinds of admixtures are included as part of ASTM Designation: C 494, Type S?**

Type S of ASTM C 494 is for specific performance admixtures. Specific performance admixtures are defined as admixtures that provide a desired performance characteristic(s) other than reducing water content, or changing the time of setting or both. The performance characteristics typically include shrinkage reducing admixtures (SRA’s), viscosity modifying admixtures (VMA’s) and mitigation of ASR (lithium).

**90-4.06 Required Use of Air-Entraining Admixtures**

**25. What are air-entraining admixtures and when are they used?**

Air entraining admixtures are used to encapsulate minute air bubbles in concrete to improve durability in freeze/thaw environments. The space made by these air bubbles provides room for water to expand during freeze/thaw cycles without damaging the concrete. Air entraining admixtures are generally required in Caltrans Climate Area III.

**90-4.07 Optional Use of Air-Entraining Admixtures**

**26. Why would the contractor use an air-entraining admixture in an area where it is not required?**

Air entrainment typically contains air bubble sizes ranging from 10 µm – 1 mm. Fine aggregate grading ranges from 75 µm – 4.75 mm. Because of the overlap, when air-entraining is included, less fine aggregate is needed. In locations where fine aggregate is expensive or scarce, air-entraining admixture can be used as an

economical partial replacement. Entrained air also enhances the workability of fresh concrete allowing for additional reduction in water demand.

## **90-6 MIXING AND TRANSPORTING**

### **90-6.01 General**

#### **27. What, in addition to the material and strength requirements, gives the inspector grounds for rejection of concrete?**

##### General

Section 90-6.01 – “Concrete shall be homogenous and thoroughly mixed, and there shall be no lumps or evidence of undispersed material”

In addition to the general application above, the Resident Engineer has the authority of the engineer which gives the rights as follows:

Section 5-1.01 – “The Engineer shall decide all questions which may arise as to the quality or acceptability of materials furnished and work performed and as to the manner of performance and rate of progress of the work; all questions which may arise as to the interpretation of the plans and specifications; all questions as to the acceptable fulfillment of the contract on the part of the Contractor; and all questions as to compensation. The Engineer’s decision shall be final, and the Engineer shall have authority to enforce and make effective those decisions and orders which the Contractor fails to carry out promptly.”

Below are specific applications for use in structures and pavement.

##### For use in structures:

Section 51-1.09 – “Concrete shall be placed and consolidated by methods that will not cause segregation of the aggregates and will result in a dense homogeneous concrete which is free of voids and rock pockets.”

Section 51-1.18 Surface Finishes – “If rock pockets, in the opinion of the Engineer, are of such an extent or character as to affect the strength of the structure materially or to endanger the life of the steel reinforcement, the Engineer may declare the concrete defective and require the removal and replacement of the portions of the structure affected.”

##### For use in paving:

Section 40-1.07B – “Slip-form paving equipment shall spread, consolidate and screed freshly placed concrete in such a manner that a minimum of handwork will be required to produce a dense homogeneous pavement true to cross section and profile.”

**90-6.03 Transporting Mixed Concrete**

**28. What are the minimum and maximum amounts of mixing allowed for concrete?**

Normally when the concrete is transported in a truck mixer or agitator, the concrete must be discharged before 1.5 hours after batching and before 250 revolutions of the drum or blades. There are a few exceptions to this limit: A shorter time may be required by the engineer if the concrete delivery temperature is above 85 °F or if there are other conditions, such as high atmospheric temperatures or added accelerators that contribute to rapid stiffening of the concrete. A longer time is allowed, 2 hours or 300 revolutions, if a retarding admixture is used provided the temperature of the concrete is not above 85 °F. More revolutions are allowed, 300, but no additional time, if a high range water reducer, Type F or G, is added at the job site.

**90-6.04 Time or Amount of Mixing**

**29. How much mixing is required for a batch of concrete?**

In stationary or paving mixers the minimum mixing time is established by trials to produce a uniform mixture. Normally the minimum time allowed is 90 seconds but when trials are witnessed by the engineer, the engineer may authorize a reduction, to as low as 50 seconds. In transit mixers the minimum revolutions at mixing speed is established by the manufacturer of the mixer.

**90-6.06 Amount of Water and Penetration**

**30. When can water be added?**

Water can only added to the mix only at the batch plant and can not exceed the specified design amount. A best management practice is to adjust the water as needed at the batch plant until the required slump is met without exceeding the water required for the mix design.

**31. Why is the amount of free water limited and how is this calculation performed?**

The amount of free water is limited, to provide maximum water to cementitious materials ratio (w/cm). The specification states “The amount of free water used in concrete shall not exceed 310 pounds per cubic yard, plus 20 pounds for each required 100 pounds of cementitious material in excess of 550 pounds per cubic yard.” This calculates to maximum w/cm ratios as follows:

| Concrete Type     | Minimum Cementitious Material (lbs) | Free Water Allowed                       | Implied Maximum w/cm ratio |
|-------------------|-------------------------------------|------------------------------------------|----------------------------|
| Minor             | 505                                 | 310                                      | $\frac{310}{505} = 0.61$   |
| Structure “Other” | 590                                 | $310 + \frac{(590-550)}{100} * 20 = 318$ | $\frac{318}{590} = 0.54$   |
| Bridge Deck       | 675                                 | $310 + \frac{(675-550)}{100} * 20 = 335$ | $\frac{335}{675} = 0.50$   |

Note also that Section 90-4.10 requires that liquid admixtures used at dosages greater than ½ gallon per cubic yard shall be considered water when determining the total amount of free water.

When the contractor elects to use more cementitious material than the minimum, additional water is allowed at the rate of 30 pounds per 100 pounds of cementitious material. In the example of a bridge deck that the contractor uses 750 lb/CY of cementitious material the free water allowed is  $310 + (675-530/100) \times 20 + (750-675/100) \times 30 = 357.5$ . The implied maximum w/cm ratio is  $357.5/750 = 0.477$ .

## 90-9 COMPRESSIVE STRENGTH

### 90-9.01 General

**32. When does this section apply?**

This section applies to all concrete that is designated by compressive strength. This includes all concrete with a specified compressive strength greater than 3600 psi as stated in Section 90-1.01, or when the concrete is specified to be designated by compressive strength.

## **90-10 MINOR CONCRETE**

### **90-10.01 General**

#### **33. What are the differences between minor concrete and general concrete?**

Minor concrete has decreased amounts of cementitious materials when compared to general concrete because of the lower required strengths. Recycled aggregate (up to 100%) is also allowed for use in minor concrete as long as it meets all other aggregate requirements, whereas it is not allowed in general concrete. Minor concrete also has the additional allowance to use Rice Hull Ash (RHA) as an SCM per SSP S8-C02 (This SSP will appear in Section 8-2 of the project specifications).

#### **34. What is the purpose of the Table in Section 90-10.01?**

The specification does not have a maximum limit on the amount of SCM's allowed in concrete. When the minimum amount of any one SCM is used, we are confident that the required strength will be met. When more than the minimum SCM is used and the Portland cement is reduced, there is a chance that the required strength may not be achieved depending on the exact proportions..

## **SECTION 90 MISCELLANEOUS QUESTIONS**

#### **35. What Standard Special Provisions (SSP's) are typically used with the Section 90 "Portland Cement Concrete" specifications and when are each of them used?**

There are three key SSP's that are used with the Section 90 specifications. They are S8-C02 "Portland Cement Concrete" S8-C04 "Corrosion Control for Portland Cement Concrete" and S8-C05 "Freezing Condition Requirements." S8-C02 is used for minor concrete in Climate Areas I or II. S8-C04 is used in corrosive environments as shown in Memo-To-Designer Figure 10-5(1): Corrosive Environment Diagram, Bridge Design Specification Tables 8.22.1 and 8.22.2 for structure concrete, and Highway Design Manual Tables 855.4A and 855.4B for all other concrete. S8-C05 is used in Climate Area III, when the structure involved is a bridge, a box culvert, concrete pavement, or is critical with regard to the safety of the traveling public.

#### **36. What items are the inspector and/or engineer supposed to receive from the contractor at the start of and throughout a job?**

As every concrete job varies, requirements from one job to the next may be different. This list includes items that are required for a typical concrete placement.

1. Copy of mix design (See Appendix B for submittal information)
2. Shrinkage Test Data (90-1.01)
3. Cementitious Material Certificates of Compliance
4. Admixture Certificate of Compliance
5. Aggregate Testing Results
  - a. Coarse Aggregate

- i. Cleanness Value CT 227
    - ii. Los Angeles Rattler CT 211
  - b. Aggregate Gradation
    - i. Sand Equivalent CT 217
    - ii. Organic Impurities CT 213
    - iii. Relative Mortar Strengths CT 515
6. Slump Test results (if specified)
7. Penetration Test results (if specified)
8. Weighmaster Certificates
  - a. Check proportioning variations
9. Concrete samples (cylinders, beams, etc.) as needed per specifications
10. Curing compound samples (if required)

**37. Where can a pre-approved concrete mix design be found?**

Caltrans does not provide pre-approved mix designs for use in projects. California is very diverse climatically making it impractical to have any one mix design for all instances. Also, material sources can always change leading to an inconsistent final product.

## **SECTION 3. Q&A SCM's**

### **1. What is the purpose of using SCM's?**

The use of SCM's was first initiated by the need for ASR mitigation, as these materials mitigate the reactivity of reactive aggregates. In addition to this, Assembly Bill #32 (AB 32) established a statewide greenhouse gas (GHG) emissions cap, to reduce the level of emissions in the year 2020 to 1990 levels. Cement production is responsible for about 7% of the GHG emissions in California and given that cement can be replaced by SCM's, these emissions can be reduced substantially. Also, as some SCM's are naturally occurring or byproducts of industrial processes, they can be cheaper than cement. Another benefit of using SCM's is that they modify several different properties of concrete including strength, workability, permeability, and durability. See Table #1 of this section for insight on property changes.

### **2. Which SCM's are allowed for use in the specifications?**

The SCM's that are allowed in all Caltrans concrete are Ground Granulated Blast Furnace Slag (GGBFS), Fly Ash, Ultra Fine Fly Ash, Silica Fume, Metakaolin and Raw or Calcined Natural Pozzolans. In addition to those above, Rice Hull Ash (RHA) is allowed in minor concrete. As stated in the specifications, these materials must be on the Pre-Qualified Products List prior to use.

### **3. What are the differences between binary and ternary mixes?**

The only difference between a binary and ternary mix is how many cementitious materials, including cement, are used. A binary mix is a mixture of two cementitious materials, typically portland cement and one SCM. A ternary mixture has three cementitious materials, typically portland cement and any two SCM's. Should four or five SCM's be used in a mix, they are referred to as quaternary and quinary respectively. The most common ternary combinations are: cement, Fly ash and Silica Fume; and cement, GGBFS and Fly Ash.

### **4. What properties should be anticipated when using binary mixtures?**

Binary mixtures will vary depending on the type, amount, and supplier of SCM used. Though there are variations, in general, each individual SCM will have the same basic properties. Table 1 lists several key properties of SCM's for freshly mixed and hardened concrete. Also, Appendix A provides a 1-page Quick Reference Sheet for the more common SCM's presenting the physical properties, chemical composition, when, where, and why they should be used, typical dosage rates, and notable extras.



**\*Table 1 – Effects of SCM’s on Concrete Properties**

| Property (Freshly Mixed) | GGBFS | Fly Ash | Metakaolin | Silica Fume | Rice Hull Ash |
|--------------------------|-------|---------|------------|-------------|---------------|
| Water Requirement        | ▼     | ▼▼      | ▲          | ▲▲          | ▼             |
| Workability              | ▲     | ▲       | ▼          | ▼▼          | ▼             |
| Initial Set Time         | ▼     | ▼▲      | ◄►         | ◄►          | ▼             |
| Final Set Time           | ◄►    | ◄►      | ◄►         | ◄►          | ▼             |
| Heat of Hydration        | ▼     | ▼       | ▼          | ◄►          | ◄►            |
| Finishability            | ▲     | ▲       | ▲          | ▼▲          | ▼             |
| Pumpability              | ▲     | ▲       | ▲          | ▲           | ▲             |
| Plastic Shrinkage        | ◄►    | ◄►      | ◄►         | ▲           | ◄►            |

| Property (Hardened)                      | GGBFS   | Fly Ash           | Metakaolin | Silica Fume | Rice Hull Ash |
|------------------------------------------|---------|-------------------|------------|-------------|---------------|
| Early Strength                           | ▼       | ▼                 | ▲▲         | ▲▲          | ▲             |
| Long Term Strength                       | ▲       | ▲                 | ▲▲         | ▲▲          | ▲             |
| Permeability                             | ▼       | ▼                 | ▼▼         | ▼▼          | ▼             |
| Sulfate Resistance                       | ▲▲      | ▲▲                | ▲          | ▲           | ▲             |
| Chloride Resistance                      | ▲       | ▲                 | ▲▲         | ▲▲          | ▲             |
| ASR Mitigation                           | ▲▲      | ▲▲                | ▲          | ▲           | ▲             |
| Finished Color (compared to 100% cement) | Lighter | Lighter or Darker | Lighter    | Darker      | Darker        |

\*Table adapted from “*Integrated Materials and Construction Practices for Concrete Pavement*”

**Legend:**

- ▲ - Increased / Improved
- ▲▲ - Significantly Increased / Improved
- ▼ - Reduced / Decreased
- ▼▼ - Significantly Reduced / Decreased
- ▼▲ - Effect Varies
- ◄► - No Change

5. According to the chart, GGBFS and fly ash have decreased early strengths and higher long term strengths. How long does it take for the higher strengths to begin?

This property can vary greatly depending on the source, manufacturer and the various SCM ratios. There is no set time at which SCM concrete catches up. Typically SCM concrete has comparable strengths anywhere from 7 days for slag to 28 days for fly ash. Figure 1 shows typical strength development curves for binary mixtures based on a 2008 Caltrans SCM Study at the SCM ratios given.

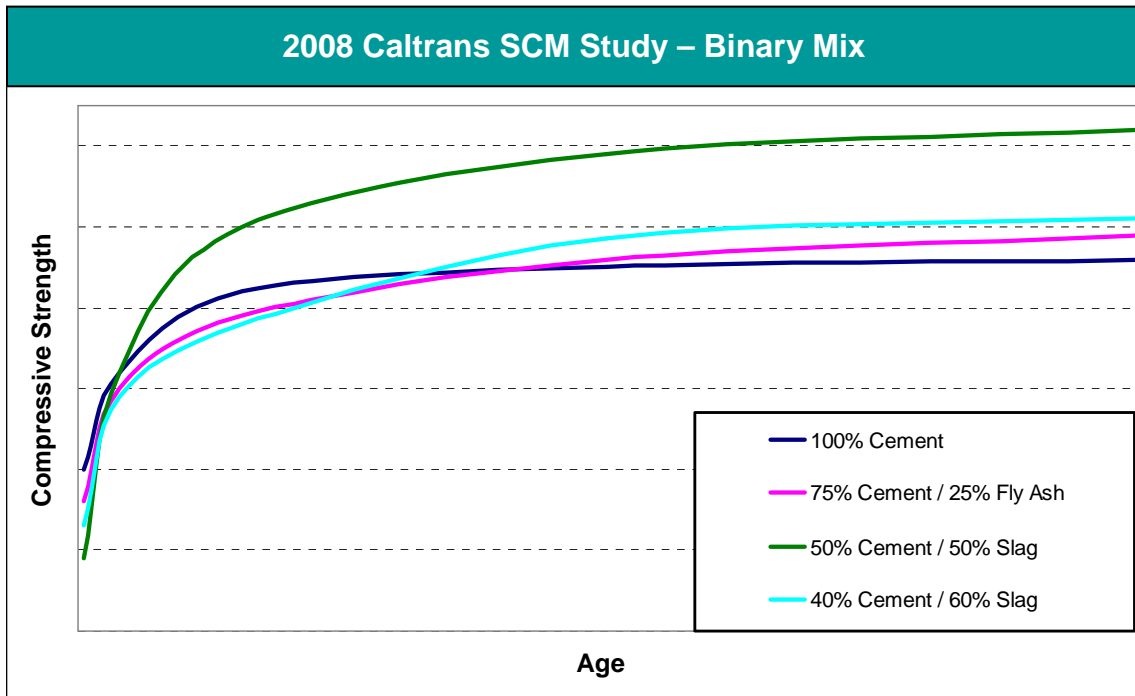


Figure 1 – SCM Study Binary Mix

## 6. What properties should be anticipated when using ternary mixtures?

Properties of ternary mixtures are more difficult to generalize than for binary mixtures. The properties will vary greatly depending on which SCM is used, how much of each SCM is used, and the amount of cement used. Ternary mixes should be thoroughly tested prior to placement on any job to determine these characteristics. For reference, the ternary mixtures tested in the 2008 Caltrans SCM Study attained comparable strength to the reference sample at approximately 28 days. Figure 2 below represents this data.

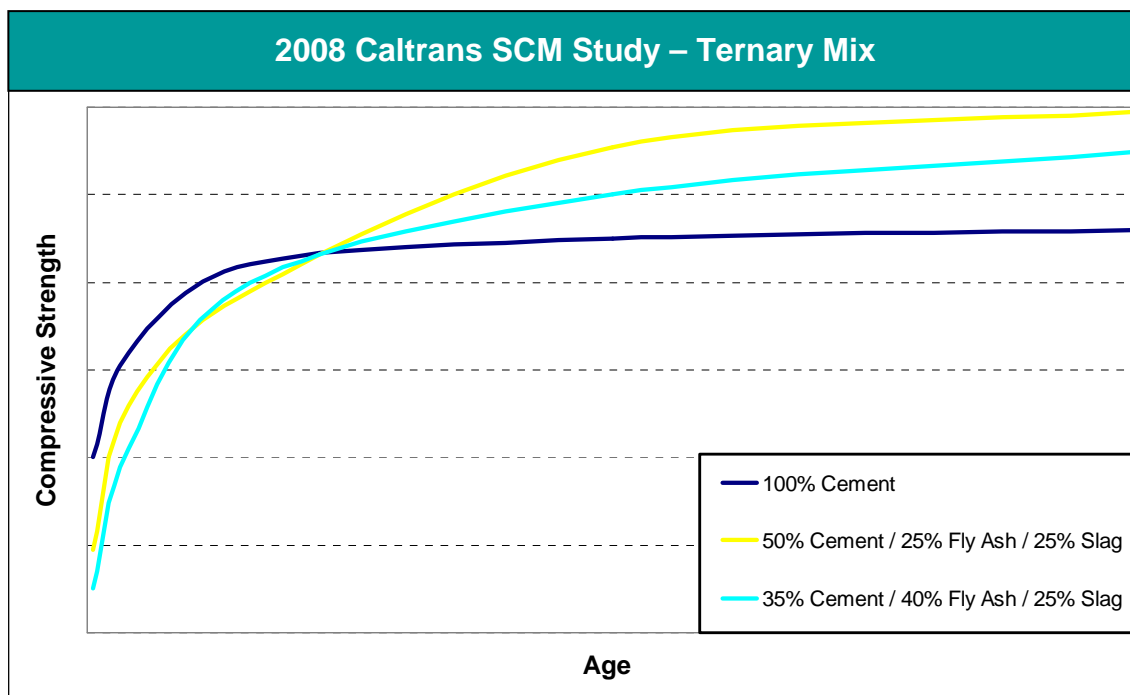


Figure 2 – SCM Study Ternary Mix

## 7. Where can additional information be found on each of the different types of SCM's?

Most SCM's have organizations or associations that have published information on their products and can be found at their respective websites. The American Concrete Institute (ACI) has also published documents on the use of SCM's along with the National Ready Mixed Concrete Association (NRMCA) and the Transportation Research Board (TRB). Links to some of these resources have been provided below for reference:

### Slag Cement Association

<http://www.slagcement.org/>

### American Coal Ash Association

<http://www.aaa-usa.org/>

### Silica Fume Association

<http://www.silicafume.org/>

### American Concrete Institute

<http://www.concrete.org/>

### National Ready Mixed Concrete Asso.

<http://www.nrmca.org/>

### Transportation Research Board

<http://www.trb.org/>

## **SECTION 4. Q&A ADMIXTURES**

### **1. What is the purpose of using Admixtures?**

Admixtures are used to enhance the properties of concrete in the plastic and hardened state.

### **2. What Admixtures are allowed for use in the specifications?**

The admixtures allowed in Caltrans concrete are Type A, B, C, D, F, G, and S chemical admixtures, air-entraining admixtures, and lithium nitrate. Lithium nitrate is normally considered a Type S chemical admixture, however additional requirements have been placed on this type of admixture to ensure ASR resistance.

### **3. What properties can be expected when using admixtures?**

Chemical admixtures are added to concrete during mixing to modify fresh or hardened concrete properties such as air content, workability, or setting time. Admixtures are also used to maintain specific properties during concreting operations or under unusual conditions. An admixture's effectiveness depends on many mix factors, including cementitious materials properties, water content, aggregate properties, concrete materials proportions, mixing time and intensity, and temperature.

### **4. What are chemical admixtures, and what are they used for?**

There are eight types of chemical admixtures classified as follows:

Type A - Water reducing admixture. This is used to reduce the quantity of mixing water at a given workability or increase workability at a given water content.

Type B - Retarding admixture used for increasing setting time of concrete.

Type C - Accelerating admixture used for decreasing setting time and to develop early strength gain.

Type D - Water reducing and retarding admixture has the effects of both A and B.

Type E - Water reducing and accelerating admixtures has the effects of both A and C.

Type F - Water reducing, high range admixture used to reduce the quantity of mixing water required to produce concrete of a given consistency by 12% or more, and can be used to produce high slump or flowing concrete.

Type G - Water reducing, high range, and retarding admixtures are used to reduce the quantity of mixing water required to produce concrete of given consistency by 12% or more and retard setting times of concrete.

Type S - Specific performance admixtures used for shrinkage reduction, ASR mitigation, and viscosity modification and any other specific requirement.

**5. Are there any side effects of using Chemical Admixtures?**

Yes. There can be numerous side effects when using admixture materials which are why manufacturer's recommendations should always be followed. For example, overdoses of water reducers may retard or prevent setting. Also, for every 1% entrained air, concrete loses about 5% of its compressive strength. A water reducing admixture is also known for increasing the early and ultimate strengths as the lower water requirement decreases the water/cementitious materials ratio.

**6. Are there compatibility issues with Admixtures?**

Some chemical admixtures may affect the effectiveness of other chemical admixtures. The batching sequence may also have an impact on the effectiveness of each of the admixtures. It is important that the contractor conducts tests prior to construction to ensure that the selected combination of admixtures performs as intended.

**7. Do chemical admixtures perform the same with all SCM's?**

No. They will also perform slightly differently with different brands and types of cements. Additionally, a manufacturer must provide a compatibility statement with the types and amounts of SCM used.

**8. Do SCM's and chemical admixtures have any effect on air-entrainment?**

Each SCM and chemical admixture could have some effect on air-entrainment depending on the manufacturer, chemical composition, and dosage rate. In general, water-reducing and set-retarding chemical admixtures increase air content, high-range water reducers can increase or decrease the air content, and accelerators generally have no effect. For SCM's, Class F Fly Ash can have no effect on reduced air content, GGBFS has variable effects and Silica Fume reduces the air content. Table 1 lists several key properties of materials and effects on air-entrainment.

**\*Table 1 – Effects of Materials and Practices on Air Entrainment**

| Material/practice                    | Change                                | Effect |
|--------------------------------------|---------------------------------------|--------|
| Cement                               | Increase in cement content            | ▼      |
|                                      | Increase in fineness                  | ▼      |
|                                      | Increase in alkali content            | ▲      |
| Supplementary cementitious materials | Fly ash (especially with high carbon) | ▼▼     |
|                                      | Silica Fume                           | ▼▼     |
|                                      | Slag with increasing fineness         | ▼      |
|                                      | Metakaolin                            | ◄►     |
| Aggregates                           | Increase in maximum size              | ▼      |
|                                      | Sand content                          | ▲      |
| Chemical admixtures                  | Water reducers                        | ▲      |
|                                      | Retarders                             | ▲      |
|                                      | Accelerators                          | ◄►     |
|                                      | High-range water reducers             | ▲      |
| W/CM                                 | Increase W/CM                         | ▲      |
| Slump                                | Increase in slump up to 6 in.         | ▲      |
|                                      | High slump (> 6 in.)                  | ▼      |
|                                      | Low slump (< 3 in.)                   | ▼      |
| Production                           | Batching                              | ▼▲     |
|                                      | Increased mixer capacity              | ▲      |
|                                      | Mixer speeds to 20 rpm                | ▲      |
|                                      | Longer mixing time                    | ▲      |
| Transport and delivery               | Transport                             | ▼      |
|                                      | Long Hauls                            | ▼      |
|                                      | Retempering (not allowed)             | ▲      |
| Placing and finishing                | Belt conveyers                        | ▼      |
|                                      | Pumping                               | ▼▼     |
|                                      | Prolonged internal vibration          | ▼      |
|                                      | Excessive finishing                   | ▼      |

\*Table adapted from “*Integrated Materials and Construction Practices for Concrete Pavement*”

**Legend:**

- ▲ - Increased / Improved
- ▲▲ - Significantly Increased / Improved
- ▼ - Reduced / Decreased
- ▼▼ - Significantly Reduced / Decreased
- ▼▲ - Effect Varies
- ◄► - No Change

## **REFERENCES**

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### **GROUND GRANULATED BLAST FURNACE SLAG**

Slag Cement Association  
PO Box 866  
Woodstock, GA 30188  
770-517-8119 office  
770-517-8119 fax

### **THE SILICA FUME ASSOCIATION**

38860 Sierra Lane, Lovettsville, VA 20180  
Tel: 540.822.9455 Fax: 540.822.9456

### **PORTLAND CEMENT ASSOCIATION**

Design and Control of Concrete Mixtures, 14th Edition  
S. Kosmatka, B. Kerkhoff, W. Panarese  
Date: 2002 (rev. 2008)

### **INTEGRATED MATERIALS AND CONSTRUCTION PRACTICES FOR CONCRETE PAVEMENT: IMCP**

National Concrete Pavement Technology Center/  
Center for Transportation Research and Education  
Iowa State University  
2711 South Loop Drive, Suite 4700  
Ames, IA 50010-8664





## **APPENDIX A.**

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### **SCM QUICK REFERENCE**

|                 |     |
|-----------------|-----|
| Class F Fly Ash | A-1 |
| GGBF Slag       | A-2 |
| Metakaolin      | A-3 |
| Rice Hull Ash   | A-4 |
| Silica Fume     | A-5 |

The following pages contain information that is generic about the various types of material. Chemical compositions indicated are within typical ranges of the type of material discussed, individual samples may vary widely from the values indicated.



## FLY ASH – CLASS F *Quick Reference*

### Definition

Class F fly ashes are pozzolans. Fly ash is primarily silicate glass containing silica, alumina, calcium, and iron (the same primary components of cement) and is a byproduct of coal burning in power plants.

### Physical / Chemical Properties

Designations: ASTM C-618 / AASHTO M 295

Specific Gravity (range): 1.9-2.8  
Color: Grey or Tan  
Blaine Fineness: ~ 420 m<sup>2</sup>/kg  
Loss on ignition: 2.8 %

Typical Chemical Composition:

- Silica: 52 %
- Alumina: 23 %
- Iron Oxide: 11 %
- Calcium Oxide: 5 %
- Sulfate: 0.8 %
- Sodium Oxide: 1 %
- Potassium Oxide: 2 %

### Effects on Concrete

Some properties of freshly mixed concrete using Class F Fly Ash are: longer set time, improved workability and finishability, lower heat of hydration, improved pumping capabilities, lower water requirement, reduced bleed water, reduced segregation, and reduced shrinkage.

Some properties of hardened concrete using Class F Fly Ash are: lower permeability which improves corrosion protection, better chloride, sulfate, and abrasion resistance, lower early strengths (1-28 days) with higher long term strength (28+ days), and ASR mitigation properties. The finished concrete may also be lighter or darker in color as fly ash colors vary from tan to dark grey.



### When, Where, & Why

Fly ash should be used in:

- Snowbound and freeze / thaw areas because of its low permeability (resistance to chloride penetration) and abrasion resistance
- High temperature zones because of its longer setting time
- Marine or sulfate rich soil environments because of its sulfate resistance
- Long life structures (pavements, bridges and buildings)
- Mass concrete pours because of lower heat of hydration
- Concrete where potential for ASR is high
- Restricts early age shrinkage cracking of concrete

### Dosage Rate

Class F Fly Ash is typically used in dosages ranging from 8 to 25 percent replacement by mass of the cementitious material.

### Notable Extras

- Reacts with calcium hydroxide making concrete stronger than with 100% cement
- Green House Gas (GHG) Credits available
- Less costly than cement



### GGBF SLAG

#### Definition

Ground Granulated Blast Furnace Slag (GGBFS) or slag cement, is a glassy, granular material, created as a byproduct of iron smelting, that has been ground to suitable fineness to have cementitious properties. Slag cement is classified in three grades: 120, 100, & 80 based on slag activity index.

#### Physical / Chemical Properties

Designations: ASTM C-989 / AASHTO M 302

Specific Gravity (range): 2.85-2.95

Color: Off-White

Blaine Fineness: ~ 400 m<sup>2</sup>/kg

Loss on ignition: 1.0 %

Typical Chemical Composition:

- Silica: 35 %
- Alumina: 12 %
- Iron Oxide: 1 %
- Calcium Oxide: 40 %
- Sulfate: 9 %
- Sodium Oxide: 0.3 %
- Potassium Oxide: 0.4 %

#### Effects on Concrete

Some properties of freshly mixed concrete using GGBFS are: Longer initial set time, improved workability and finishability, lower heat of hydration, improved pumping capabilities, a lower water requirement, and no increase or decrease in plastic shrinkage cracking.

Some properties of hardened concrete using GGBFS are: Lower permeability which provides greater corrosion protection, better chloride and sulfate resistance, lower early strengths (1-7 days) with higher long term strength (7+ days), a lighter finished color, and ASR mitigation properties. Initially it has a green hue that fades to grey after a few days exposure to air.



#### When, Where, & Why

GGBFS should be used in:

- Snowbound areas because of low permeability
- High ambient temperature zones because of longer setting time
- Marine or sulfate rich soil environments because of sulfate resistance
- Long life structures (pavements, bridges, and buildings) since higher long term strength
- Mass concrete pours because of lower heat of hydration

#### Dosage Rate

GGBFS is typically used in dosages ranging from 25% to 60% replacement by mass of the cementitious material. 25% is typically used in ternary blends while 60% is used with GGBFS by itself. 50 percent is the upper limit in concrete where maximum strength is required. Higher percentages may be used in mass concrete or if used for ASR mitigation.

#### Notable Extras

- Compatible with fly ash and silica fume in ternary concrete blends.
- Green House Gas (GHG) Credits available
- Less costly than cement



### METAKAOLIN

#### Definition

Metakaolin, a natural pozzolan, is derived from the calcination of a high-purity kaolin clay. The product is then ground to between 1 - 2  $\mu\text{m}$  (about 10 times finer than cement).

#### Physical / Chemical Properties

Designations: ASTM C-618 / AASHTO M 295

Specific Gravity (range): 2.5-2.6

Color: Off-White - Grey

Blaine Fineness:  $\sim 19,000 \text{ m}^2/\text{kg}$

Loss on ignition: 0.7 %

Typical Chemical Composition:

- Silica: 53 %
- Alumina: 43 %
- Iron Oxide: 0.5 %
- Calcium Oxide: 0.1 %
- Sulfate: 0.1 %
- Sodium Oxide: 0.05 %
- Potassium Oxide: 0.4 %

#### Effects on Concrete

Some properties of freshly mixed concrete using Metakaolin are: no significant change in set time, higher water requirement, reduced workability, decreased heat of hydration, increased finishability, and improved pumpability.

Some properties of hardened concrete using Metakaolin are: significantly increased early and long-term strengths, increased flexural strength, reduced permeability (improving corrosion protection), better chloride, sulfate, and abrasion resistance, and ASR mitigation properties.



#### When, Where, & Why

Metakaolin should be used in:

- Snowbound and freeze / thaw areas because of its low permeability (resistance to chloride penetration) and abrasion resistance
- Low temperature zones because of its shorter setting time
- Chemically aggressive environments as permeability coefficient reduced by order of magnitude
- Marine or sulfate rich soil environments because of its sulfate resistance
- Long life structures (pavements, bridges and buildings) as increased strengths
- Denser concrete since average particle size under 1 - 2  $\mu\text{m}$

#### Dosage Rate

Metakaolin is typically used in dosages ranging from 5 to 10 percent replacement by mass of the cementitious material.

#### Notable Extras

- Used extensively to improve visual appeal of structures because of its lighter color and similar properties to silica fume.
- More costly than cement





### RICE HULL ASH

#### Definition

Rice Hull Ash (RHA) is a pozzolanic material formed as a byproduct of the rice milling process. RHA exhibits several similar properties to that of silica fume as it is comparable in chemical composition.

#### Physical / Chemical Properties

|                               |                    |
|-------------------------------|--------------------|
| Designations:                 | AASHTO M 321       |
| Specific Gravity (range):     | 2.05-2.2           |
| Color:                        | Grey-Black         |
| Fineness:                     | 5-10 microns (dia) |
| Loss on ignition:             | 1.72 %             |
| Typical Chemical Composition: |                    |
| • Silica:                     | 90 %               |
| • Alumina                     | -                  |
| • Iron Oxide                  | 0.21 %             |
| • Calcium Oxide               | 0.22 %             |
| • Sodium Oxide                | 0.01 %             |
| • Potassium Oxide             | 0.04 %             |

#### Effects on Concrete

Some properties of freshly mixed concrete using Rice Hull Ash are: longer initial set time, comparable final set time, lower water requirement, decreased workability, no change in heat of hydration, increased pumpability, and decreased finishability.

Some properties of hardened concrete using Rice Hull Ash are: increased early and long-term strengths, reduced permeability (improving corrosion protection), increased chloride resistance, increased sulfate resistance, increased abrasion resistance, and ASR mitigation properties.



#### When, Where, & Why

Rice Hull Ash should be used in:

- Snowbound and freeze / thaw areas because of its low permeability (resistance to chloride penetration) and abrasion resistance
- Marine or sulfate rich soil environments because of sulfate resistance
- Areas or concretes where Alkali-Silica Reactivity (ASR) is expected as RHA can reduce expansion up to 95%
- Long life structures (pavements, bridges and buildings) since later strength increased
- Denser concrete due to reduced pore size

#### Dosage Rate

Rice Hull Ash (RHA) is typically used in dosages ranging from 5 to 15 percent replacement by mass of the cementitious material.

#### Notable Extras

- Economic substitute for cement without strength sacrifice
- Approximately 1/3<sup>rd</sup> the bulk weight of cement
- Less costly than cement



## SILICA FUME

### Definition

Silica Fume is an extremely fine pozzolanic material formed as a byproduct of the silicon and ferrosilicon industries and produced through the electric arc furnaces. Silica Fume particles are typically 100 times finer than that of cement.

### Physical / Chemical Properties

Designations: ASTM C-1240 / AASHTO M 307

Specific Gravity (range): 2.2-2.6  
Color: Light - Dark Grey  
Blaine Fineness: ~ 20,000 m<sup>2</sup>/kg  
Loss on ignition: 2.94 %

Typical Chemical Composition:

- Silica: 90 %
- Alumina: 0.4 %
- Iron Oxide: 0.4 %
- Calcium Oxide: 1.6 %
- Sulfate: 0.4 %
- Sodium Oxide: 0.5 %
- Potassium Oxide: 2.2 %

### Effects on Concrete

Some properties of freshly mixed concrete using Silica Fume are: no significant change in set time, significantly increased water requirement, significantly decreased workability, no change in heat of hydration, increased pumpability, and decreased finishability.

Some properties of hardened concrete using Silica Fume are: significantly increased early and long-term strengths, reduced permeability (improving corrosion protection), significantly increased chloride resistance, better sulfate resistance, and ASR mitigation properties.



### When, Where, & Why

Silica Fume should be used in:

- Snowbound and freeze / thaw areas because of its low permeability (resistance to chloride penetration) and abrasion resistance
- Chemically aggressive environments as permeability coefficient reduced by order of magnitude.
- Low temperature zones because of its shorter setting time
- Marine or sulfate rich soil environments because of its sulfate resistance
- Long life structures (pavements, bridges and buildings) as increased strength
- Denser concrete as 100 times finer than cement

### Dosage Rate

Silica Fume is typically used in dosages ranging from 3 to 10 percent replacement by mass of the cementitious material.

### Notable Extras

- Used significantly in ternary mixes with fly ash or GGBFS to improve durability of mix
- Green House Gas (GHG) Credits available
- More costly than cement



## **APPENDIX B.**

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### **SPECIFICATION SAMPLE CALCULATIONS**

|                                                              |      |
|--------------------------------------------------------------|------|
| Mix Design Submittal Checklist                               | B-1  |
| Example #1 Bridge Deck Binary Mix                            | B-2  |
| Example #2 Typical Ternary Mix                               | B-8  |
| Example #3 High Volume SCM Mix Binary                        | B-10 |
| Example #4 – Bridge Deck in Climate Area III – Ternary Mix   | B-12 |
| Example #5 – Bridge Column in Climate Area III - Ternary Mix | B-14 |
| Example #6 - Typical Minor Concrete Mix                      | B-17 |

The following pages contain generic samples and information about the various types of material.



## MIX DESIGN SUBMITTAL CHECKLIST

### A. Materials Verification

1. **Cement**
  - On Pre-Qualified Product’s List (PQPL)?       Yes    No   (If No, reject mix)
2. **Blended Cement**
  - Blended Cement Specified?       Yes    No   (If No, skip to #3)
  - All Blending Materials on PQPL?       Yes    No   (If No, reject mix)
3. **Supplementary Cementitious Materials**
  - All SCM’s on PQPL?       Yes    No   (If No, reject mix)
  - Fly Ash CaO content verified?       Yes    No   (If No, reject mix)
4. **Aggregate**
  - Proposed Gradation given?       Yes    No   (If No, reject mix)
  - Within Grading Limits?       Yes    No   (If No, reject mix)
  - On PQPL?       Yes    No   (If Yes, reduced “X” allowed in Section B)
5. **Chemical Admixtures**
  - Chemical Admixtures Specified?       Yes    No   (If No, skip to #6)
  - On PQPL?       Yes    No   (If No, reject mix)
  - Dosage Verified (per plans or manufacturer’s recommendations)       Yes    No
6. **Air-entraining Admixtures**
  - Air-Entraining Admixture Specified?       Yes    No   (If No, skip to #7)
  - On PQPL?       Yes    No   (If No, reject mix)
  - Dosage Verified (per plans or manufacturer’s recommendations)       Yes    No
7. **Lithium Nitrate Admixtures**
  - Lithium Nitrate Admixture Specified?       Yes    No   (If No, skip to #8)
  - On Pre-Qualified Product’s List?       Yes    No   (If No, reject mix)
  - Dosage Verified (per plans or manufacturer’s recommendations)       Yes    No


### B. Mix Design Testing and Calculations

8. **Shrinkage Test Compliance (for paving, bridge decks, and approach slabs)**
  - Shrinkage Test Data Verified       Yes    N/A    No   (If No, reject mix)
  - Verify “similar” mix design as needed per 90-1.01       Yes    N/A    No   (If No, reject mix)
9. **Check Minimum Specified Amount of Cementitious Material**       OK    Reject
  - Include Blended Cement, 90-2.01, and reduction per 90-4.05 if necessary
10. **Check Amount of Free Water (90-6.06)**       OK    N/A    Reject
11. **Check Required Use of SCM Equations**       OK    N/A    Reject
12. **Check Strength Development Equation**       OK    N/A
13. **Check Corrosion Control Specifications**       OK    N/A    Reject
14. **Check Freezing Condition Equations**       OK    N/A    Reject

|                                                                     |
|---------------------------------------------------------------------|
| <input type="checkbox"/> Approved <input type="checkbox"/> Rejected |
|---------------------------------------------------------------------|



Example #1 – Bridge Deck - Binary Mix



## A&A Concrete Supply, Inc.

8272 Berry Avenue  
Sacramento, CA 95828 Phone (916) 383-3756 Fax (916) 383-8427 www.AAReadyMix.com

**CONTRACTOR:** RM Harris Co.      **MIX DESIGN:** z5685210

**PROJECT:** I-80 & North Texas Street Interchange 5246      **DATE:** 12/30/2008

**MIX USE:** Caltrans Sec. 90 "Class I Concrete"      **MAX SIZE AGG:** 1" x #4 (25.4mm x 4.75mm)

**PLACEMENT METHOD:** Check with your pumping Contractor      **PENETRATION CT 533:** 50mm      **50mm Max Sec 6.06**

**BATCH PLANT:** Fairfield #39      **W/(C+P):** 0.43

**SLUMP:** 4" Max

**MATERIAL SOURCES:**

**CEMENT:** ASTM C-150 Type II Modified

**FLY ASH:** ASTM C-618 - Class "F"

**COARSE AGG:** Teichert Aggregates - Esparto

**FINE AGG:** Teichert Aggregate - Esparto

**ADMIXTURES:** Master Builders / Degussa Admixtures

**CALTRANS SECTION 90 "Class I" CONCRETE MIX DESIGN FOR 1.0 CUBIC YARD (SSD)**

| AGGREGATE GRADATION *           |      |      |          |      |     |          |       |          | SP.GR.      | ABS.VOL. | BATCH W' Weight |        |             |      |         |
|---------------------------------|------|------|----------|------|-----|----------|-------|----------|-------------|----------|-----------------|--------|-------------|------|---------|
| (% Passing U.S. Standard Sieve) | No.2 | No.3 | Caltrans | No.4 | WCS | Caltrans | COMB. | Caltrans |             | CU.FT.   | LBS./CY         | Kg./CM |             |      |         |
| SIZE:                           | 0%   | 60%  | Sec.90   | 0%   | 40% | Sec.90   | 100%  | Sec.90   |             |          |                 |        |             |      |         |
| Agg%:                           |      |      | 3.02     |      |     | 3.03     |       | 3.04     | Cement:**   | 6.82     | Sks.            | 3.15   | 2.45        | 481  | 287     |
| 2.0"-50mm                       | 100  | 100  | 100      | 100  | 100 |          | 100   |          | Fly Ash:    | 25%      | % Rep.          | 2.30   | 1.12        | 160  | 95      |
| 1.5" 37.5mm                     | 98   | 100  | 100      | 100  | 100 |          | 100   | 100      | 1.5" Agg.:  | 0        | % Agg           | 2.75   | 0.00        | 0    | 0.0     |
| 1.0" 25mm                       | 22   | 100  | 88-100   | 100  | 100 |          | 100   | 90-100   | 1.0" Agg.:  | 60       | % Agg           | 2.67   | 11.11       | 1851 | 1098    |
| 3/4" - 19mm                     | 8    | 85   | 70-100   | 100  | 100 |          | 91    | 55-100   | 3/8" Agg.:  | 0        | % Agg           | 2.70   | 0.00        | 0    | 0.0     |
| 3/8" 9.75mm                     | 2    | 15   | 0-30     | 96   | 100 | 100      | 49    | 45-75    | W/C. Sand:  | 40       | % Agg           | 2.63   | 7.53        | 1236 | 733     |
| #4 - 4.75mm                     |      | 1    | 0-16     | 14   | 100 | 95-100   | 41    | 35-60    | Water:      | 32.9     | Gal.            | 1.00   | 4.39        | 274  | 163     |
| #8 - 1.18mm                     |      | 0    |          | 4    | 91  | 65-95    | 36    | 27-45    | Total Air % | 1.5%     |                 |        | 0.41        | ---- |         |
| #16 - 1.18mm                    |      |      |          | 1    | 58  | 48-68    | 23    | 20-35    | Totals:     |          |                 | 27.00  |             | 4002 | 2376    |
| #30 600µm                       |      |      |          |      | 35  | 26-44    | 14    | 12-25    |             |          |                 |        |             |      |         |
| #50 300µm                       |      |      |          |      | 16  | 10-22    | 6     | 5-15     | ADMIXTURE:  |          |                 |        |             |      |         |
| #100 -150µm                     |      |      |          |      | 5   | 1-15     | 2     | 1-8      | 322-n       | 5        | oz / cwt.       |        | oz / cu.yd. | 32.1 | MI / Cm |
| #200 - 75µm                     |      |      |          |      | 1.2 | 0-10     | 0.5   | 0-4      |             |          |                 |        |             |      | 1240    |
| S.E                             |      |      |          |      | 87  | 75 Min   |       |          |             |          |                 |        |             |      |         |
| C.V.                            |      | 88   | 75 Min   |      |     |          |       |          |             |          |                 |        |             |      |         |

**PERTINENT PROPERTIES:**      Cementitious Factor: 6.8      W/(C+P) x wt : 0.43

Unit Weight, pcf: (ASTM C-138)      (Sacks / Cubic Yard)

148.2

Notes:

\* Aggregate gradations provided by aggregate producer      \*\* Cement Content reduced by 5% per Section 90-4.05 Par 2.

X-VALUES COARSE AGG: 19mm = 85      9.75mm = 15

X-VALUES FINE AGG: 1.18mm = 58      600µm = 35      300µm = 16

**Additional Information Submitted with Mix Design:**

- Cement Source:** CEMEX – Cupertino, Type II
- SCM Source:** Headwater Resources, Inc. Type (a) Centralia Fly Ash
- Fly Ash CaO content:** 8.0%
- Shrinkage Test Results:** Passed with similar mix approved within 3 years
- Climate Area:** I
- Structure in Corrosive Environment:** No
- Concrete to be used for:** Bridge Deck
- Chemical Admixture:** Master Builders Pozzoloth 322 N (Water Reducing Admixture)





## Example 1 continued

**A. Material Verification****1. Cement**

- On Pre-Qualified Product's List (PQPL)?  Yes  No (If No, reject mix)

**\*Cement verified on PQPL.**

**2. Blended Cement**

- Blended Cement Specified?  Yes  No (If No, skip to #3)  
○ All Blending Materials on PQPL?  Yes  No (If No, reject mix)

**\*No Blending Used**

**3. Supplementary Cementitious Materials**

- All SCM's on PQPL?  Yes  No (If No reject mix)  
○ Fly Ash CaO content verified?  Yes  No (If No reject mix)

**\*Fly Ash source verified on PQPL. CaO content verified at 8.0%**

**4. Aggregate**

- Proposed Gradation given?  Yes  No (If No reject mix)  
○ Within Grading Limits?  Yes  No (If No reject mix)  
○ On PQPL?  Yes  No (If Yes, reduced "X" allowed in Section B)

**\*Aggregate gradation verified versus specifications. Aggregate source verified on PQPL (innocuous) resulting in X = 1.8 for calculations. See #11.**

**5. Chemical Admixtures**

- Chemical Admixtures Specified  Yes  No (If No skip to #6)  
○ On PQPL?  Yes  No (If No reject mix)  
○ Dosage Verified (per plans or manufacturer's recommendations)  Yes  No

**\*Manufacturer's recommended dosage is 3-7 fl oz / cwt. Mix design calls for 5 fl oz / cwt.**

**6. Air-entraining Admixtures**

- Air-Entraining Admixture Specified?  Yes  No (If No skip to #7)  
○ On PQPL?  Yes  No (If No reject mix)  
○ Dosage Verified (per plans or manufacturer's recommendations)  Yes  No

**\*No Air-Entraining Admixtures Used**



### Example 1 continued

**7. Lithium Nitrate Admixtures**

- Lithium Nitrate Admixture Specified?  Yes  No (If No skip to #8)
- On PQPL?  Yes  No (If No reject mix)
- Verify dosage (per plans or manufacturer’s recommendations)  Yes  No

**\*No Lithium Nitrate Admixtures Used**



**8. Shrinkage Test Compliance (for paving, bridge decks, and approach slabs)**

- Shrinkage Test Data Verified  Yes  N/A  No (If No, reject mix)
- Verify “similar” mix design as needed per 90-1.01  Yes  N/A  No (If No, reject mix)

**\*Shrinkage test results/data verified with a previous similar mix**



**9. Check Minimum Specified Amount of Cementitious Material**  OK  Reject

- Include Blended Cement, 90-2.01, and reduction per 90-4.05 if necessary

**\*Bridge decks, as specified per 90-1.01, require a minimum of 675 lbs/CY of cementitious material. Per section 90-4.05, a reduction of 5% is allowed in mixes that include a water reducing admixture. This mix does include a water reducing admixture which brings the minimum specified amount of cementitious material (MC) down to 641 lbs/CY.**

$$MC = 641 \text{ lbs/CY}$$

**The total amount of cementitious material (TC) used is calculated by adding the amount of cement and SCM’s (in lbs/CY) from the provided mix design.**

$$TC = 481 + 160 = 641$$

$$641 \geq 641$$



**The total amount (or actual amount) of cementitious material (TC) is greater than or equal to the minimum amount of cementitious material (MC), therefore the amount of cementitious material is OK.**

## Example 1 continued

## 10. Check Amount of Free Water (90-6.06)

 OK  N/A  Reject

\*Per section 90-6.06, the amount of free water must be less than 310 lbs/CY, plus 20 lbs for each required 100 lbs of cementitious material in excess of 550 lbs/CY. This calculates as follows:

$$FW \leq 310 + \left( \frac{MC - 550}{100} \right) * 20$$

$$310 + \left( \frac{641 - 550}{100} \right) * 20 = 328.2 \text{ lbs/CY}$$

$$FW = 274 \text{ lbs/CY} \quad 274 \leq 328.2 \quad \checkmark \text{ OK}$$

\*The amount of free water (given in mix design) is less than the maximum calculated, therefore amount of free water is OK.

## 11. Check Required Use of SCM's Equations (if necessary)

 OK  N/A  Reject

## Step 1. Check Equation 1 (90-2.01C)

~~$$\frac{(25 * UF) + (12 * FA) + (10 * FB) + (6 * SL)}{MC} \geq X$$~~ , X = 1.8

UF, FB, and SL go to zero as Silica Fume, Metakaolin, Ultra Fine Fly Ash, GGBFS, and Fly Ash with 15% CaO content are not used. X is equal to 1.8 as determined in #4.

$$\frac{(12 * 160)}{641} = 3.0$$

$$3.0 \geq 1.8 \quad \checkmark \text{ OK}$$

Left side of Equation 1 is equal to 3.0. 3.0 is greater than 1.8, therefore equation is satisfied.

### Example 1 continued

#### Step 2. Calculate MSCM for Equation 2 (90-2.01C)

MSCM defined as “the minimum sum of SCM’s that satisfies Equation 1.” Since there is only one SCM used, solve equation for FA using  $X = 1.8$  and  $MC = 641$  as before.

$$FA = \frac{1.8 * 641}{12} = 96.2$$

$$FA = 96.2 = MSCM$$

This is the minimum sum of SCM’s that satisfies Equation 1.

#### Step 3. Check Equation 2 (90-2.01C)

$$MC - MSCM - PC \geq 0$$

Per equation 2, the left side of the equation must be greater than 0.

$$641 - 96.2 - 481 = 63.8$$

$$63.8 \geq 0 \quad \checkmark \text{ OK}$$

Left side of equation is equal to 63.8. 63.8 is greater than 0, therefore equation is satisfied. Equations 1 and 2 are both satisfied, therefore the amount of SCM’s used in the mix design is adequate.

## Example 1 continued

12. Check Strength Development Equation (if necessary)
- 
- OK
- 
- N/A

Verify allowed Strength Development Time per SSP S8-C02. If the left side of the equation is greater than 7, 56 days is allowed for the concrete to obtain the minimum required compressive strength.

$$\frac{(\cancel{41 * UF}) + (19 * F) + (\cancel{11 * SL})}{TC} \geq 7$$

UF and SL go to zero as Silica Fume, Metakaolin, Ultra Fine Fly Ash, and GGBFS are not used.

$$\frac{(19 * 160)}{641} = 4.7, 4.7 \text{ is not } \geq 7.$$

Left side of equation is equal to 4.7. 4.7 is not greater than 7 therefore 56 days is not allowed for concrete to obtain the minimum required compressive strength. The time allowed shall be per Section 90-1.01.

13. Check Corrosion Control Specifications (if necessary)
- 
- OK
- 
- N/A
- 
- Reject

Corrosion Control for Portland Cement Concrete is Not Applicable as this structure is not in a corrosive environment per the Specifications.


14. Check Freezing Condition Equation's (if necessary)
- 
- OK
- 
- N/A
- 
- Reject

The Freezing Condition Requirements are Not Applicable as this structure is not in Climate Area III


Approved  Rejected




### Example #2 - Typical Ternary Mix



755 STOCKTON AVE • SAN JOSE, CALIFORNIA 95126-1837  
TELEPHONE (408) 293-6272 FAX (408) 404-1075  
June 12, 2009





Supplies for the Concrete Contractor  
(408) 947-8606

**Mix Design # D20115RA**

Below are listed current proportions for the mix as produced from the Central Concrete production facility scheduled to be delivered to the job site. Note that adjustments to proportions may be necessary to maintain contract performance in the case of delivery from another source or in the event of material changes necessitated by supply issues.

**Mix Description :** 590LBS\*CA DOT\*EF TECHNOLOGY      **W/C Ratio :** 0.48  
**Design Strength :**      **Slump :** 4.00 in  
**Usage :**

| MATERIAL                               | SSD         | VOLUME       |
|----------------------------------------|-------------|--------------|
| <b>CEMENT :</b> ASTM C-150, Type II/V  | 295         | 1.50         |
| <b>SLAG :</b> ASTM C-989, GGBFS        | 177         | 0.98         |
| <b>FLYASH :</b> ASTM C-618, Class F    | 118         | 0.82         |
| <b>SAND :</b> SAND ASTM C-33           | 1451        | 8.77         |
| <b>AGGREGATE :</b> ASTM C33 #57        | 1720        | 9.70         |
| <b>AIR :</b> 2.50 % +/- 1.00           |             | 0.68         |
| <b>WATER :</b> ASTM C1602-04, C1603-04 | 284         | 4.55         |
| <b>ADMIXTURE :</b>                     | <b>4045</b> | <b>27.00</b> |

ASTM C-260 AIR ENTRAINMENT 1.0 ozs./cwt +/- 0.5

**Given / Known**

Climate Area:

II

Minimum Specified Cementitious Material (90-1.01):

MC = 590 lbs/CY

Aggregate Type: "Non-Innocuous"

X = 3

Fly Ash CaO content: 10%

**Step 1:** Check minimum specified cementitious material (MC) content versus total cementitious material (TC).

$$TC = 295 + 177 + 118 = 590$$

$$590 \geq 590 \quad \checkmark \text{ OK}$$

**Step 2:** Check Equation 1 (90-2.01C)

$$\frac{(25 * UF) + (12 * FA) + (10 * FB) + (6 * SL)}{MC} \geq X$$

UF and FB go to zero as Ultra Fine Fly Ash, Silica Fume, Metakaolin, and Fly Ash or Natural Pozzolan with CaO content up to 15% are not used.

$$\frac{(12 * 118) + (6 * 177)}{590} \geq 3, \quad 4.2 \geq 3 \quad \checkmark \text{ OK}$$

## Example 2 continued

### Step 3: Calculate MSCM for Equation 2 (90-2.01C)

MSCM defined as “the minimum sum of SCM’s that satisfies Equation 1”

Use equation from Step 2. Starting from left to right, enter the SCM values, up to the actual amount in the mix, until the left side of the equation is equal to 3.

$$\frac{(12 * 118) + (6 * 59)}{590} = 3$$

For this example, all fly ash and 59 of the 177 lbs/CY of the slag is needed.

MSCM is the sum of the values above.

$$\text{MSCM} = 118 + 59 = 177$$

### Step 4: Check Equation 2

$$\text{MC} - \text{MSCM} - \text{PC} \geq 0$$

$$590 - 177 - 295 = 118$$

$$118 \geq 0 \quad \checkmark \text{ OK}$$

### Step 5: Verify allowed Strength Development Time (S8-C02).

$$\frac{\cancel{(41 * UF)} + (19 * F) + (11 * SL)}{TC} \geq 7$$

$$\frac{(19 * 118) + (11 * 177)}{590} \geq 7, 7.1 \geq 7 \quad \checkmark \text{ OK}^*$$

\*Since equation is satisfied, high SCM content is verified and up to 56 days allowed to obtain minimum required compressive strength.

**Mix Design satisfies all equations and shall be allowed for use as specified.**

**Example #3 – High Volume SCM Mix – Binary**

**BODE CONCRETE**  
696 AMADOR STREET  
SAN FRANCISCO CA 94124  
415-920-6740

05/27/2009

-----  
CONCRETE MIX DESIGN  
-----

FOR :  
  
SAN FRANCISCO

---

MIX # 501X70    4000 PSI    5.0 SK    1" AD-70% SLAG    3.50 Slump

|                   | VOLUME<br>CU.FT. | SPECIFIC<br>GRAVITY | S.S.D.<br>WEIGHTS |        |
|-------------------|------------------|---------------------|-------------------|--------|
| AIR               | 0.405            | 0.00                | 1.5               | VOL    |
| WATER             | 3.878            | 1.00                | 242.0             | LBS    |
| TYPE II MODIFIED  | 0.717            | 3.15                | 141.0             | LBS    |
| SLAG              | 1.818            | 2.90                | 329.0             | LBS    |
| 1" SECHELT AGG    | 10.900           | 2.72                | 1850.0            | LBS    |
| SECHELT SAND      | 3.628            | 2.65                | 600.0             | LBS    |
| ANGEL ISLAND SAND | 5.594            | 2.65                | 925.0             | LBS    |
| TYPE A WATER RED. |                  | 0.00                | 3.0               | OZ/CWT |

-----  
Pumpable Mix Designs should be approved by your pumping service prior to placement relative to his equipment and line size capability

**Given / Known**

Climate Area:  
I

Minimum Specified  
Cementitious Material  
(90-1.01):

MC = 470.0 lbs/CY

Aggregate Type:  
"Non-Innocuous"

X = 3

**Step 1:** Check minimum specified cementitious material (MC) content versus total cementitious material (TC).

$$141 + 329 = 470$$

$$470 \geq 470 \quad \checkmark \text{ OK}$$

**Step 2:** Check Equation 1 (90-2.01C)

~~$$\frac{(25 * UF) + (12 * FA) + (10 * FB) + (6 * SL)}{MC} \geq X$$~~

UF, FA, and FB go to zero as Silica Fume, Metakaolin, Ultra Fine Fly Ash, and Fly Ash are not used.

$$\frac{(6 * 329)}{470} \geq 3, \quad 4.2 \geq 3 \quad \checkmark \text{ OK}$$





### Example 3 continued

**Step 3:** Calculate MSCM for Equation 2 (90-2.01C)

MSCM defined as “the minimum sum of SCM’s that satisfies Equation 1”

Use equation from step 2. Since there is only one SCM used, set equation equal to 3 and solve for SL.

$$\frac{(6 * \boxed{\text{SL}})}{\boxed{470}} = 3$$

MSCM is equal to SL since only one SCM.

$$\text{SL} = \text{MSCM} = \boxed{235}$$

**Step 4:** Check Equation 2

$$\text{MC} - \text{MSCM} - \text{PC} \geq 0$$

$$\boxed{470} - \boxed{235} - \boxed{141} = 94$$

$$94 \geq 0 \quad \checkmark \text{ OK}$$

**Step 5:** Verify allowed Strength Development Time (S8-C02).


~~$$\frac{(41 * \text{UF}) + (19 * \text{F}) + (11 * \text{SL})}{\text{TC}} \geq 7$$~~

$$\frac{(11 * \boxed{329})}{\boxed{470}} \geq 7, 7.7 \geq 7 \quad \checkmark \text{ OK}^*$$


\*Since equation is satisfied, high SCM content is verified and up to 56 days allowed to obtain minimum required compressive strength.


**Mix Design satisfies all equations and shall be allowed for use as specified.**

Example #4 – Bridge Deck in Climate Area III – Ternary Mix



756 STOCKTON AVE • SAN JOSE, CALIFORNIA 95126-1837  
TELEPHONE (408) 293-6272 FAX (408) 404-1075  
June 12, 2009





Supplies for the Concrete Contractor  
(408) 947-8606

**Mix Design # D10115RA**

Below are listed current proportions for the mix as produced from the Central Concrete production facility scheduled to service the project referenced. Note that adjustments to proportions may be necessary to maintain contract performance in the case of delivery from another production location or in the event of material changes necessitated by supply issues.

Mix Description : 675LBS\*CA DOT\*EF TECHNOLOGY      W/C Ratio : 0.42  
Design Strength :      Slump : 4.00 in

Usage :

| MATERIAL           | SSD                     | VOLUME                 |
|--------------------|-------------------------|------------------------|
| CEMENT :           | ASTM C-150, Type II/V   | 337      1.71          |
| SLAG :             | ASTM C-989, GGBFS       | 203      1.12          |
| FLYASH :           | ASTM C-618, Class F     | 135      0.94          |
| SAND :             | SAND ASTM C-33          | 1372      8.30         |
| AGGREGATE :        | ASTM C33 #57            | 1720      9.70         |
| AIR :              | 2.50 % +/- 1.00         | 0.68                   |
| WATER :            | ASTM C1602-04, C1603-04 | 284      4.55          |
| <b>ADMIXTURE :</b> |                         | <b>4051      27.00</b> |

ASTM C-260 AIR ENTRAINMENT 1.0 ozs./cwt +/- 0.5

**Given / Known**

Climate Area: III  
Minimum Specified Cementitious Material (90-1.01):

MC = 675 lbs/CY

Aggregate Type: "Non-Innocuous"

X = 3

Fly Ash CaO content: 10%

**Step 1:** Check minimum specified cementitious material (MC) content versus total cementitious material (TC).

$$TC = 337 + 203 + 135 = 675$$

$$675 \geq 675 \quad \checkmark \text{ OK}$$

**Step 2:** Check Equation 1 (S8-C05)

~~$$\frac{(25 * UF) + (12 * FA) + (10 * FB) + (6 * SL)}{TC} \geq X$$~~

UF and FB go to zero as Ultra Fine Fly Ash, Silica Fume, Metakaolin, and Fly Ash or Natural Pozzolan with CaO content up to 15% are not used.

$$\frac{(12 * 135) + (6 * 203)}{675} \geq 3, \quad 4.2 \geq 3 \quad \checkmark \text{ OK}$$



## Example 4 continued

Step 3: Check Equation 2 (S8-C05)

$$\frac{4 * (FA + FB)}{TC} \leq 1$$

$$\frac{4 * (135 + 0)}{675} \leq 1$$

$$0.8 \leq 1 \quad \checkmark \text{ OK}$$

Step 4: Check Equation 3 (S8-C05)

$$\frac{(10 * UF)}{TC} \leq 1$$

$$\frac{10 * (0)}{675} \leq 1$$

$$0 \leq 1 \quad \checkmark \text{ OK}$$

Step 5: Check Equation 4 (S8-C05)

$$\frac{2 * (\cancel{UF} + FA + \cancel{FB} + SL)}{TC} \leq 1$$

$$\frac{2 * (135 + 203)}{675} \leq 1$$

$$1.0 \leq 1 \quad \checkmark \text{ OK}$$

Step 6: Check Equation 5 (S8-C05)

$$\frac{27 * (TC - MC)}{MC} \leq 5$$

$$\frac{27 * (675 - 675)}{675} \leq 5$$

$$0 \leq 5 \quad \checkmark \text{ OK}$$

**Mix Design satisfies all equations and shall be allowed for use as specified.**

**Example #5 – Bridge Column in Climate Area III - Ternary Mix**

**BODE CONCRETE**  
696 AMADOR STREET  
SAN FRANCISCO CA 94124  
415-920-6740

05/27/2009

-----  
**CONCRETE MIX DESIGN**  
-----

FOR :  
  
SAN FRANCISCO

---

MIX # 601X      5000 PSI    6.0 SK    1" AD 30% SLAG      4.00 Slump

|                   | VOLUME<br>CU.FT. | SPECIFIC<br>GRAVITY | S.S.D.<br>WEIGHTS |        |
|-------------------|------------------|---------------------|-------------------|--------|
| AIR               | 0.405            | 0.00                | 1.5               | VOL    |
| WATER             | 4.135            | 1.00                | 258.0             | LBS    |
| TYPE II MODIFIED  | 1.577            | 3.15                | 310.0             | LBS    |
| SLAG              | 0.934            | 2.90                | 169.0             | LBS    |
| FLYASH            | 0.582            | 2.34                | 85.0              | LBS    |
| 1" SECHELT AGG    | 9.427            | 2.72                | 1600.0            | LBS    |
| SECHELT SAND      | 3.931            | 2.65                | 650.0             | LBS    |
| ANGEL ISLAND SAND | 6.011            | 2.65                | 994.0             | LBS    |
| TYPE A WATER RED. |                  | 0.00                | 3.0               | OZ/CWT |

---

Pumpable Mix Designs should be approved by your pumping service prior to placement relative to his equipment and line size capability

**Given / Known**

Climate Area:  
III

Minimum Specified  
Cementitious Material  
(90-1.01):

MC = 590 lbs/CY

5% Adjusted Minimum  
Specified Cementitious  
Material (90-4.05):

MC = 561 lbs/CY

Aggregate Type:  
"Non-Innocuous"

X = 3

Fly Ash CaO content:  
10%

**Step 1:** Check minimum specified cementitious material (MC) content versus total cementitious material (TC).

$$TC = 310 + 169 + 85 = 564$$

$$564 \geq 561 \quad \checkmark \text{ OK}$$

### Example 5 continued

**Step 2:** Check Equation 1 (90-2.01C)

$$\frac{(25 * UF) + (12 * FA) + (10 * FB) + (6 * SL)}{MC} \geq X$$

UF and FB go to zero as Silica Fume, Metakaolin, Ultra Fine Fly Ash, and Fly Ash with CaO content up to 15% are not used.

$$\frac{(12 * 85) + (6 * 169)}{561} \geq 3, 3.62 \geq 3 \quad \checkmark \text{ OK}$$

**Step 3:** Calculate MSCM for Equation 2 (90-2.01C)

MSCM defined as “the minimum sum of SCM’s that satisfies Equation 1”

Use equation from Step 2. Starting from left to right, enter the SCM values, up to the actual amount in the mix, until the left side of the equation is equal to 3.

$$\frac{(12 * 85) + (6 * 110.5)}{561} = 3$$

For this example, all fly ash and 110.5 of the 169 lbs/CY of the slag is needed.

MSCM is the sum of the values above.

$$\text{MSCM} = 85 + 110.5 = 196$$

**Step 4:** Check Equation 2

$$MC - \text{MSCM} - PC \geq 0$$

$$561 - 196 - 310 = 55$$

$$55 \geq 0 \quad \checkmark \text{ OK}$$

**Example 5 continued**

**Step 5:** Check Cementitious Material requirement of (S8-C05) since this is not an exposed surface in climate area III

$$\frac{\cancel{(41 * UF)} + (19 * F) + (11 * SL)}{TC} \leq 7$$


UF goes to zero as silica fume, metakaolin and ultra fine fly ash not used in mix

$$\frac{(19 * 85) + (11 * 169)}{564} \leq 7, 6.16 \leq 7 \quad \checkmark \text{ OK*}$$


\*SCM content upper limit verified for use in freezing condition

**Mix Design satisfies all equations and shall be allowed for use as specified.**


Example #6 - Typical Minor Concrete Mix



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(408) 947-8606

**Mix Design # D20115RA**

Below are listed current proportions for the mix as produced from the Central Concrete production facility scheduled to service...  
Note that adjustments to proportions may be necessary to maintain contract performance in the case of delivery from another...  
the event of material changes necessitated by supply issues.

**Mix Description :** 590LBS\*CA DOT\*EF TECHNOLOGY      **W/C Ratio :** 0.48  
**Design Strength :**      **Slump :** 4.00 in  
**Usage :**

| MATERIAL           |                        | 260         | VOLUME       |
|--------------------|------------------------|-------------|--------------|
| <b>CEMENT :</b>    | ASTM C-150, Type II/V  | 260         | 1.50         |
| <b>SLAG :</b>      | ASTM C-989, GGBFS      | 150         | 0.98         |
| <b>FLYASH :</b>    | ASTM C-618, Class F    | 100         | 0.82         |
| <b>SAND :</b>      | SAND ASTM C-33         | 1451        | 8.77         |
| <b>AGGREGATE :</b> | ASTM C33 #57           | 1720        | 9.70         |
| <b>AIR :</b>       | 2.50 % +/-1.00         |             | 0.68         |
| <b>WATER :</b>     | ASTM C1602-04,C1603-04 | 284         | 4.55         |
| <b>ADMIXTURE :</b> |                        | <b>4045</b> | <b>27.00</b> |

ASTM C-260 AIR ENTRAINMENT 1.0 ozs./cwt +/- 0.5

**Given / Known**

Climate Area:

II

Minimum Specified  
Cementitious Material  
(90-1.01):

MC = 505 lbs/CY

Aggregate Type:

“Non-Innocuous”

X = 3

Fly Ash CaO content:  
10%

**Step 1:** Check minimum specified cementitious material (MC) content versus total cementitious material (TC).

$$TC = 260 + 150 + 100 = 510$$

$$510 \geq 505 \quad \checkmark \text{ OK}$$

**Step 2:** Check Equation 1 (90-2.01C)

$$\frac{(25 * UF) + (12 * FA) + (10 * FB) + (6 * SL)}{MC} \geq X$$

UF and FB go to zero as Ultra Fine Fly Ash, Silica Fume, Metakaolin, and Fly Ash or Natural Pozzolan with CaO content up to 15% are not used.

$$\frac{(12 * 100) + (6 * 150)}{505} \geq 3, \quad 4.2 \geq 3 \quad \checkmark \text{ OK}$$

### Example 6 continued

**Step 3:** Calculate MSCM for Equation 2 (90-2.01C)

MSCM defined as “the minimum sum of SCM’s that satisfies Equation 1”

Use equation from Step 2. Starting from left to right, enter the SCM values, up to the actual amount in the mix, until the left side of the equation is equal to 3.

$$\frac{(12 * 100) + (6 * 52.5)}{505} = 3$$

For this example, all fly ash and 52.5 of the 150 lbs/CY of the slag is needed.

MSCM is the sum of the values above.

$$\text{MSCM} = 100 + 52.5 = 152.5$$

**Step 4:** Check Equation 2

$$\text{MC} - \text{MSCM} - \text{PC} \geq 0$$

$$505 - 152.5 - 260 = 92.5$$

$$92.5 \geq 0 \quad \text{OK}$$

**Step 5:** Verify allowed Strength Development Time (S8-C02).

$$\frac{\cancel{(41 * UF)} + (19 * F) + (11 * SL)}{\text{TC}} \geq 7$$

$$\frac{(19 * 100) + (11 * 150)}{510} \geq 7, 6.96 \leq 7 \quad \text{Failed*}$$

\*Since equation is **not** satisfied, high SCM content is **not** verified, 56 days required to obtain minimum required compressive strength.

**Mix Design satisfies all equations and shall be allowed for use as specified.**